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STUDIES IN DISPLAY SYMBOL LEGIBILITY: PART XI.

THE RELATIVE LEGIBILITY OF SELECTED ALPHANUMERICS IN TWO FONTS

AUGUST 1966

G. C. Kinney
D. J. Showman

Prepared for
DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 7030

Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
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FOREWORD

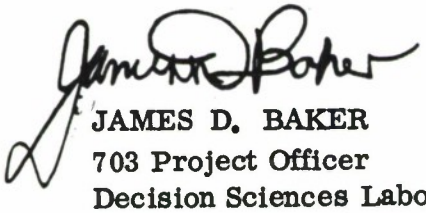
This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966; "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background Relation, and Surround Brightness on the Legibility of Capital Letters," by D. Shurtleff, B. Botha, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966; "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on the Legibility of the Common Five-Letter Words," by G. Kosmider, The MITRE Corp., Bedford, Mass., ESD-TR-65-135, May 1966; "Studies of Display Symbol Legibility, VI: Leroy and Courtney Symbols," by D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-136, May 1966; "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945-and 525-Line Resolutions," by D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-137, May 1966; "Studies of Display Symbol Legibility, VII: Legibility of Common Five-Letter Words," by G. Kosmider, M. Young, and G. Kinney, The MITRE Corp., Bedford, Mass., ESD-TR-65-385, May 1966; "Studies of Display Symbol Legibility, IX: The Effects of Resolution, Size, and Viewing Angle of Legibility," by D. Shurtleff, M. Marsetta and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-65-411, May 1966; and "Studies in Display Symbol Legibility, X: The Relative Legibility of Leroy and Lincoln/MITRE Alphanumeric Symbols," by D. J. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-115, August 1966.

ABSTRACT

Twelve of the most frequently confused alphanumeric symbols were selected from Leroy and Lincoln/MITRE (L/M) fonts and studied for their relative legibilities. Human subjects saw the symbols with five different brightness contrast ratios, and errors were recorded. The L/M font gave significantly fewer errors at all contrast ratios. It was concluded that the L/M font will yield better legibility than the Leroy font and that a greater reduction in errors can be obtained by using the L/M font than by increasing the contrast of a display using Leroy symbols.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the reports findings or conclusions. It is published only for the exchange and stimulation of ideas.



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INTRODUCTION

A large panel display system is being built for the Air Force. The specification requires that the displayed alphanumeric symbols pass a legibility test in which human subjects try to identify each symbol when it is seen briefly (in this case, for 10 milliseconds).[1] The required test calls for all 36 alphanumerics to be included, each symbol appearing several times.

The manufacturer was working out design details, especially the symbol brightness needed to pass the test, and it was time consuming to run trial tests with all of the 36 symbols. He made up an abbreviated test which used 12 of the most frequently confused symbols, namely, B, C, G, I, O, Q, S, 1, 5, 8, Ø and $, and felt that if his display showed these 12 symbols with a small enough error rate, then the display would probably pass the larger test. At the least, he expected to find out how much brightness might be needed. If his display gave too many errors at its maximum brightness, it might be possible to reduce errors by changing the designs of some of the symbols. Since he needed a standard of comparison, MITRE was asked to study the same 12 symbols in a laboratory setting using a symbol font known to be acceptably legible and to make recommendations on symbol brightness and symbol design based on the study's results.

An improved alphanumeric font, the Lincoln/MITRE (L/M) font, was available, and a comparison of the standard Leroy and L/M fonts for different values of brightness is reported in this document.

SECTION II

TESTS

ABBREVIATED TESTS

There are some reasons for believing that the abbreviated test will not accurately predict the outcome of a larger test with the whole set of 36 symbols. One reason is that, in the larger set, the selected symbols are confused with other symbols that are not in the smaller set of 12. In the abbreviated test, the subject knows that only the 12 symbols are involved. He cannot respond with the name of a symbol that is not one of the 12, even if the symbol he just saw looks to him like one that he knows is not being shown. What he would respond with, if he were free to say whatever symbol he thought he saw, is not known from the results of the abbreviated test. Therefore, it is not known what the error rate would be for the larger test.

Furthermore, if the subject failed to see enough to help him identify the symbol just shown to him in the abbreviated test, the probability of a correct guess, on the basis of chance alone, is 1 in 12. In the larger test with all 36 symbols, his chances of guessing correctly in the same circumstances are 1 in 36. Therefore, the total errors made in the abbreviated test are based on different probabilities than the errors in the larger test, and the total error for the larger test may be underestimated by the total error for the abbreviated test even for the selected 12 symbols.

Finally, the symbols that the display shows are different from the symbols in a laboratory test, and there is no guarantee that the results of tests in the two different settings will be similar. The laboratory test may indicate that certain intersymbol confusions do not occur, and

yet these confusions may happen on the display, particularly if the display deteriorates the symbols slightly, as most projector systems do. For these reasons, an abbreviated test cannot be expected to provide information that inspires confidence in predicting the outcome of the larger test with the whole symbol set.

At the same time, the abbreviated test may reveal that the error rate is too high even for the 12 symbols. In other words, if the error rate for the 12 is higher than the specification permits for the larger test with all 36 symbols, then clearly the larger test could not be passed unless something were done to reduce the errors found with the 12 alone. Furthermore, the results of the abbreviated test would indicate where confusions occur most frequently, and the symbols involved could be worked on and tested again with less time and labor than if these same confusions were found in tests with the whole set. Since the manufacturer wished to ensure the lowest possible error rate obtainable with his design, there was good sense in making the abbreviated test, and in asking for a standard of comparison.

The abbreviated test was conducted, and the errors made by subjects viewing the selected 12 symbols under conditions visually similar to those in the display situation were determined for Leroy symbols shown with white light. The brightness contrast was set at 6, 7, 8, 9, or 10, where the symbol appeared brighter than the background, and the background was held constant at 1 ft-Lambert. For these same conditions, but with the contrast at 4, 5, 6, and 8, the error rate was determined for the same 12 symbols selected from the L/M font. The error rates for each font were plotted against the values of contrast, and the intersymbol confusions were summarized in tables.

It was concluded that the error rate was significantly lower with the improved L/M font and that the differences between fonts were more marked than the differences among the contrast values. It appeared that the biggest design improvement would be obtained by altering the font. It was concluded, also, that acceptably low error rates probably require a contrast of at least 8 to 1 for Leroy, and at least 6 to 1 for L/M. Recommendations for symbol design followed from the results.

PROCEDURES AND APPARATUS

The 12 Leroy symbols were taken from the font shown in Figure 1, and the 12 similar symbols of the improved font were taken from the L/M font shown in Figure 2. In both cases, the dollar sign was designed for this study by Showman. For each font, a list was made up with the symbols occurring at random with respect to alphabetic order and with the restrictions that no symbol appear more than twice in succession and that each symbol appear exactly 10 times in the list. The symbols were drawn on white paper and photographed with the symbol clear, and the remainder of the frame opaque, on a 35 mm strip of Dupont Cronar Ortho A Litho film. By running through the film strip from each end of the strip toward the other, either one or two frames at a time, four different random sequences of the symbols were available.

The symbols were shown one at a time, to one subject at a time, until 30 symbols had been seen and called out. The subject was required to name 1 and only 1 of the 12 symbols every time 1 was shown. A rest for 1 or 2 minutes was then given the subject, followed by a second set of 30 symbols. A rest followed each fourth of the total symbols shown in each session, a session lasting approximately 20 minutes. Three subjects who had participated in many similar experiments before were given the sessions so that the font and contrast occurred in an irregular order. The brightness contrast was set at one value for each session. Thus,

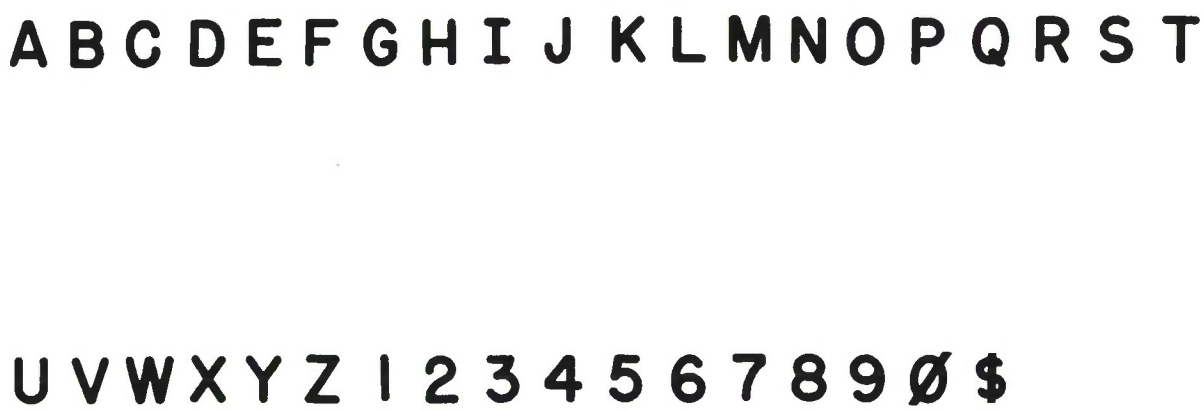

Figure 1. The Leroy Font from which the 12 Symbols were Selected for the Abbreviated Test. The $ was Designed by Showman.

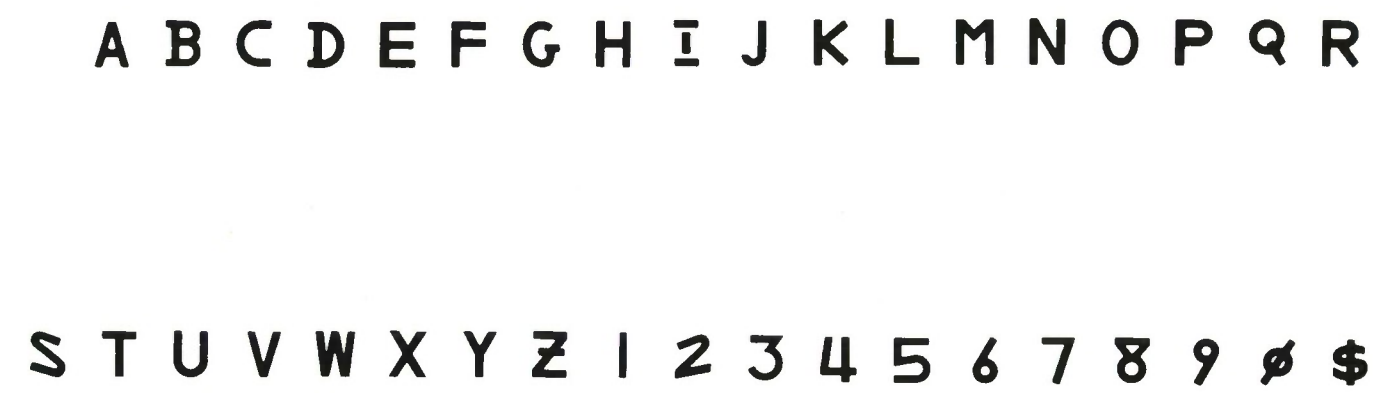

Figure 2. The Lincoln/MITRE Font from Which the 12 Symbols were Selected for Study and Comparison with Those of the Leroy Font. The $ was Designed by Showman.

there were 120 symbols per session per subject; three subjects gave a total of 360 symbol showings for each value of contrast studied.

For the Leroy font, there were 5 sessions, one each for the contrast values of 6, 7, 8, 9, and 10. For the L/M font, there were 4 sessions, one each for the contrast values of 4, 5, 6, and 8. In all sessions, the background brightness was set at 1 $\pm$ 0.1 ft-Lamberts, and the symbol brightness varied $\pm$ 0.2 ft-Lamberts from the values just stated. All brightness measurements were made with a Spectra Brightness Spot Meter, and the light was white incandescent. Each symbol was shown for 10 $\pm$ 0.1 milliseconds.

The subject sat at a table on which was placed a tachistoscope (see Figure 3). This device is essentially a T-shaped tube of rectangular cross-section arranged so that the subject can peer into one end of the cross of the T to see the other end at a distance of 54 inches. A beam splitter is arranged in the tube at the intersection of the cross and the stem of the T to reflect the image of the base of the stem of the T. The two end spaces are thus seen visually superimposed and at the same apparent distance. At the far end of the cross of the T, a rectangular hole is cut into the center of the tube's cross-section. The film bearing the symbols was passed behind this hole.

The film was lighted from behind by an external, incandescent, battery-powered, light source. Each symbol thus appeared as a bright symbol in a darker rectangle. The brightness of the symbol was varied by controlling the voltage on the light, the variation being too small in the present study to produce important changes in the color of the light. The background rectangle in which the symbol was seen included the image of the end of the stem of the T being reflected by the beam splitter. This end is covered with a fine-grained, white, styrofoam plastic, and was lighted by a second external, incandescent light. The

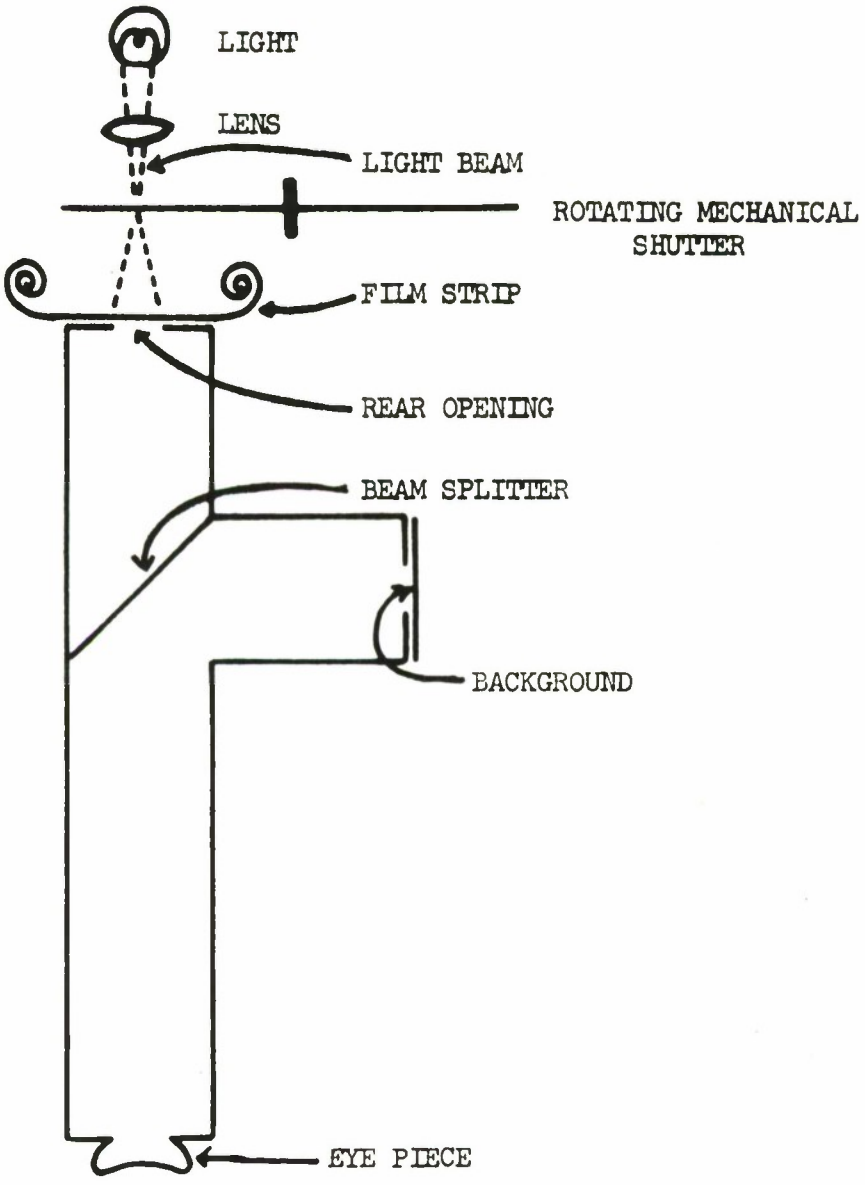

Figure 3. Sketch of the Tachistoscope Used to Expose the Symbols to the Subjects.

background brightness was controlled by varying the a-c voltage on this light source; no important changes in color being involved. The background light was left on continuously. A set of four black lines is drawn on the white plastic background, in the form of a large + sign with its center removed, and so arranged that the center of the open space between the lines is visually coincident with the center of the symbol. The open space serves as a fixation point for the eyes to focus on when the symbol is about to appear. The entire apparatus was placed in a sound-shielded room lighted dimly by white fluorescent lights.

A mechanical shutter is placed to interrupt the light which illuminates the symbol. The subject was given a switch which operates the shutter. When his syes were fixed on the fixation point, and he was ready to see the symbol appear, the subject closed the switch, which operated the shutter and exposed the symbol. In this way, the symbol was made to appear at the place where the subject's eyes were focussed. When the subject called out his response, the experimenter recorded it alongside a record of the symbol that was actually shown, advanced the film to the next planned frame, and the process was repeated for each frame.

The subject was given a photograph of the letters in the font he was to see for a session, and was told that he may refer to this illustration at any time to refresh his memory about the appearance of a symbol. The symbols each have a stroke of constant width which was one-sixth the height of the symbol, and the symbols had a height-to-width ratio of 4:3, except for the very narrow ones. The height of the symbol subtended an angle of 16 minutes of arc, approximately, at the subject's eye.

SECTION III

EVALUATION

RESULTS AND CONCLUSIONS

The total errors and the percentage error are shown for all three subjects in Table I. In Figure 4, the percentage error was rounded to the nearest whole percent and plotted against the brightness contrast (which is the same as the brightness of the symbol, since the background brightness was 1 ft-Lambert). At a contrast of 6:1, the three subjects made 22, 10, and 14 errors with the Leroy font, and 9, 1, and 3 errors, respectively, with the L/M font. At a contrast of 8:1, the errors were 6, 7, and 5 for Leroy, and 2, 2, and 0 for L/M. The errors for the two fonts at these two contrast values have not been analyzed statistically. For the purposes of this report the errors are assumed to be statistically different by inspection.

The error confusion matrix for the Leroy font at a contrast of 6:1 is in Table II. Each row of the matrix is labeled with one of the 12 symbols, and represents the symbol shown, while the columns each represent which symbol was called out in error when the row symbol was shown. For example, the letter S, which was shown a total of 30 times (as was every other symbol) was called 5 seven times, 8 one time, and $ one time. The right margin for row S shows that there were 9 errors made when S was shown. For the G and I, there were no errors. The sum of the errors in the right margin is the total error for the font with the 6:1 contrast, this being 46 as shown in Table I. For the same contrast with the L/M font, the error matrix is shown in Table III. There are so few errors in this latter table that a detailed discussion is uncalled for. In Table IV the contrast for the L/M font is 4:1, and the error rate is comparable to

Table I

Total Errors and Percentage Error for All Three Subjects for Both Fonts in All Conditions. A Dash Indicates that no Data Were Taken.

	Number of Errors		Percentage Error	
Contrast	Leroy	L/M	Leroy	L/M
10	10	-	2.8	-
9	15	-	4.2	-
8	18	4	5.0	1.1
7	26	-	7.2	-
6	46	13	12.8	3.6
5	-	23	-	6.4
4	-	46	-	12.8

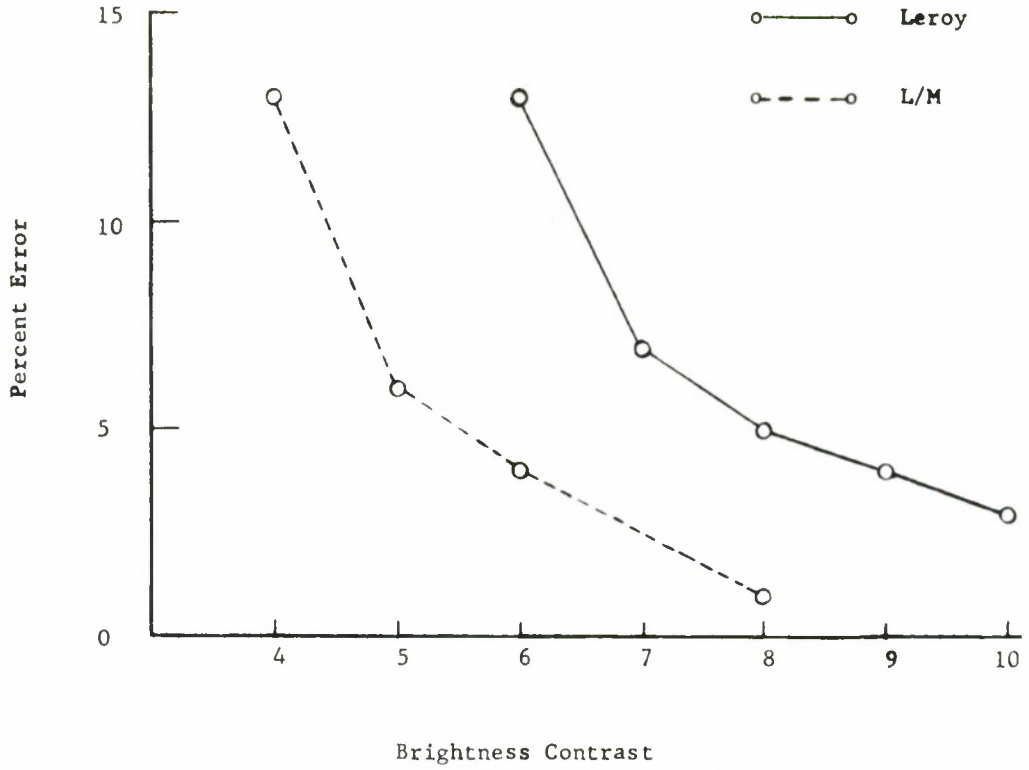

Figure 4. Percent Error for the 12 Leroy and Lincoln/MITRE Symbols Plotted Against Brightness Contrast. There were 360 Observations for Each Plotted Point, and the Error was Rounded Off to the Nearest Percent for Each Point.

that with Leroy at a contrast of 6:1, shown in Table II. These two tables may be compared in more detail as follows.

With the Leroy font at a contrast of 6:1, the B-and-8 and S-and-5 confusions, plus the C-called-G, O-called-Q and the Q-called-G confusions, accounted for 36 of the 46 errors made, ignoring all cases of 1 error (see Table II); five confusions accounted for 78.3 percent of the total error. With the L/M font, at the lower contrast of 4:1, the B-and-8 confusion, and the O-called-G, S-called-8, $-called-Ø, S-called-Q, I-called-1, Ī-called-$, 5-called-$, and $-called-8 accounted for 34 of the 46 errors, ignoring the cases of single errors; nine confusions accounted for 73.9 percent of the total error. In summary, the errors are more concentrated in particular symbols with Leroy than they are with the L/M font, the

Table II

Confusion Error Matrix for the Leroy Font at
6 ft-Lamberts, Totalled for All Three Subjects.

SYMBOL SHOWN	B	C	G	I	O	Q	S	1	5	8	Ø	$	{
B										5			5
C			10		1								11
G													0
I													0
O		1				5							6
Q			2		1								3
S									7	1		1	9
1													0
5							2					1	3
8	5		1		1								7
Ø												1	1
$										1			1
{	5	1	13	0	3	5	2	0	7	7	0	3	46

SYMBOL CALLED

Table III

Confusion Error Matrix for the L/M Font at
6 ft-Lambertts, Totalled for All Three Subjects.

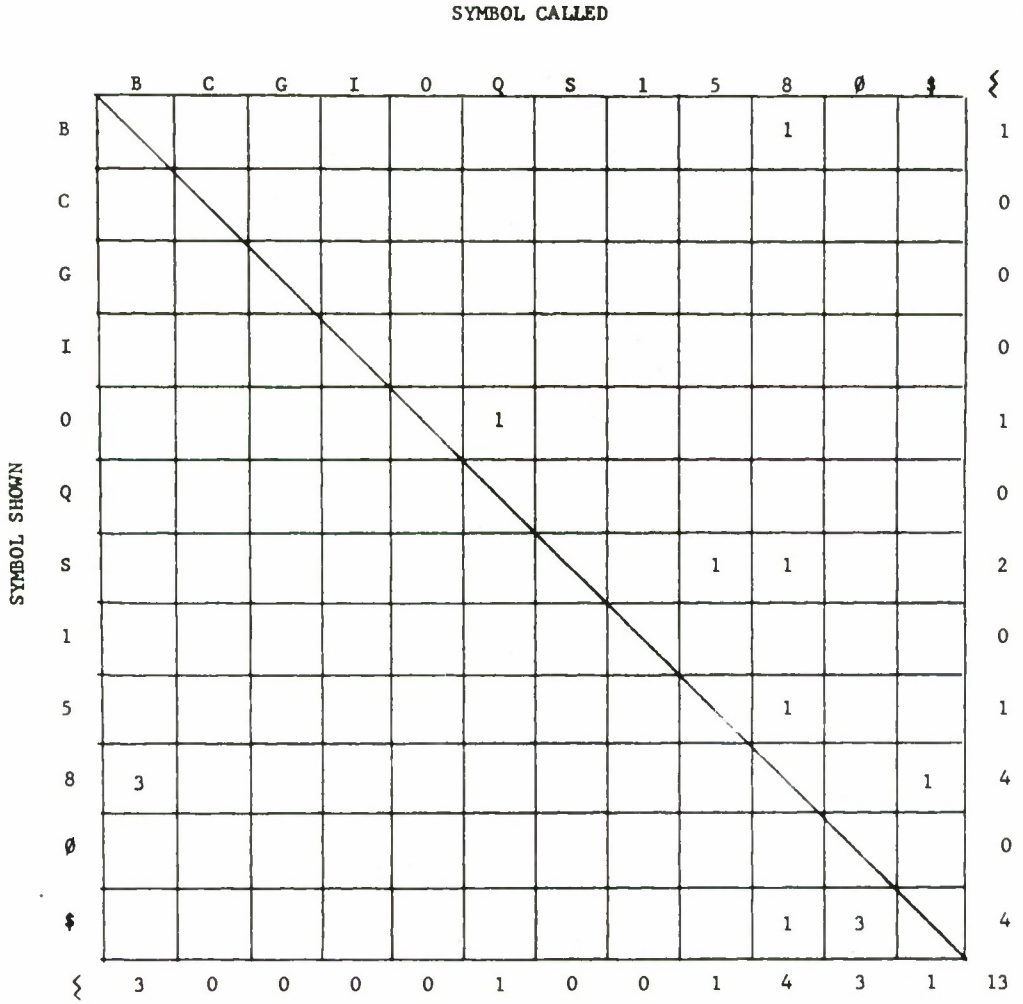

Table IV

Confusion Error Matrix for the L/M Font at
4 ft-Lamberts, Totalled for All Three Subjects.

SYMBOL SHOWN	SYMBOL CALLED												
	B	C	G	I	O	Q	S	1	5	8	Ø	$	≠
B					1					5			6
C													0
G						1							1
I								3				2	5
O			7										7
Q	1												1
S			1			3				4		1	9
1				1									1
5	1				1		1					2	5
8	2											1	3
Ø													0
$			1			1				2	4		8
≠	4	0	9	1	2	5	1	3	0	11	4	6	46

latter errors being more scattered out over the matrix. The scattering of errors with L/M and the concentration of errors for Leroy are results of special interest.

The interest stems from the fact that, if the conditions for viewing the symbols of a font are deteriorated, the error rate increases and a change takes place in the kinds of errors made. In the present case, the viewing conditions are deteriorated by holding the background brightness constant and decreasing the brightness of the symbol. When the symbol brightness (or the contrast) reaches a low value, the errors begin to spread out over the matrix, largely because every symbol is difficult to identify. If the symbols cannot be seen at all, the subject is forced to guess for every symbol, and the errors reflect nothing other than his guessing preferences. On the other hand, when the error is no greater than the 13 percent found in this study for L/M at 4:1 contrast and Leroy at 6:1 contrast, it seems reasonable to assume that the conditions have deteriorated enough to force the subject to guess only on those occasions when the symbol is difficult to identify correctly. In these circumstances, the error being the same, namely 46 in each case, the L/M font shows a wider scattering of error than does the Leroy font. Therefore, the results indicate that the errors with L/M at a contrast of 4:1 are produced more by the deteriorated conditions and less by confusing symbol design than is the case with Leroy at a contrast of 6:1. The results show that Leroy errors are related to the design of the symbols involved.

For the 12 symbols and the Leroy font selected for this study, the following conclusions seem to follow:

(1) the L/M font is more legible than the Leroy font;

(2) the errors found are related to the symbol design more in the Leroy font than in the L/M font; and

(3) it may be possible to reduce error more by changing

from Leroy to L/M than by retaining the Leroy font and increasing the brightness contrast.

DISCUSSION AND RECOMMENDATIONS

The kinds of intersymbol confusions among alphanumerics that were found in this study of a selected 12 are very similar to the confusions usually found in studies of the legibility of English numerals and capital letters.[2,3,4,5] Attempts to eliminate these confusions experimentally, and thus make the symbol set more legible, have produced the L/M font in Figure 2.[6] This font has been tested by actually asking subjects to try to identify each symbol under controlled viewing conditions. Another, and common method of designing symbols is to ask subjects, usually those considered to be experts on legibility, to rate symbols on their relative legibility, and then to select those symbols that several experts rate highly.[4] Esthetic tastes and artistic preferences are more likely to affect these judgments than they are to affect the performance of a subject in a test like that in the present study. While designing by the rating method may produce a pleasing set of symbols, there still may be a high rate of occurrence of intersymbol confusions when the symbols are eventually used on a display. Of course, the rating method does not detect or reveal symbol confusions. In addition, the rating method tends to produce symbols that are of conventional appearance, and this is one of the reasons why the same intersymbol confusions are found in legibility tests of fonts that resemble conventional symbol shapes.

For example, the symbol font shown in Figure 5 is similar to the font used by the manufacturer mentioned earlier. It appears to be the L/M, or one of its earlier forms[6], in which some of the symbols have been given a more conventional appearance. In particular, the Q, S, 8 and Ø in Figure 5 look more like typewriter symbols than they do in the L/M font. To the authors' knowledge, the font in Figure 5 was not tested

Figure 5. A Font for a Display Tube which has a Mixture of Features from the Leroy and L/M Fonts. The Q, S, 8, and Ø Differ most from the L/M Font.

by the experimental method used in the present study, nor by a method which requires the subject to perform a similar task, until after it has been built into a display tube. One would anticipate that this font will show the kinds of intersymbol confusions found with the Leroy font in this study.

It is recommended that the font in Figure 2 be used instead of a font like that in Figure 5 and that the symbols be made as closely like those in Figure 2 as is possible. In case there are equipment limitations or other requirements that do not permit an exact copying of the L/M font, or something very close to exact, it is recommended that any new symbol shape be tried out in a legibility test like that in this study before the symbols are built into the equipment.

The results of this study should be confirmed in a larger study in which all 36 of the alphanumerics are shown to the subjects. In our opinion, it is not necessary to include a dollar sign because this symbol is not likely to be used in a displayed message in such a way that it could be taken for some other symbol, and thus bring about some serious error in operator performance. If some suspiciously dangerous use of the dollar sign is contemplated or anticipated, then the symbol should be included to make a total of 37 in the larger experiment. The larger study should use subjects who are not so experienced as the three subjects in this study. Subjects who have not participated in the development of the L/M font may show different confusions than subjects who are more intimately acquainted with the details of symbol design differences. It is considered unlikely that the L/M font will fail to show itself as superior to either of the other two fonts shown in this paper.[6] Nevertheless, the larger study would amplify, and may confirm, the results of this study, and it is now being done by the present authors.

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13. ABSTRACT

Twelve of the most frequently confused alphanumeric symbols were selected from Leroy and Lincoln/MITRE (L/M) fonts and studied for their relative legibilities. Human subjects saw the symbols with five different brightness contrast ratios, and errors were recorded. The L/M font gave significantly fewer errors at all contrast ratios. It was concluded that the L/M font will yield better legibility than the Leroy font and that a greater reduction in errors can be obtained by using the L/M font than by increasing the contrast of a display using Leroy symbols.

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